Calcareous spring mires in Slovakia; Jewels in the Crown of the Mire Kingdom

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Abstract: Rich calcareous fens in Slovakia are almost exclusively restricted to the Carpathian Mountains, only few remnants occur in the lowlands. Prior to major drainage schemes, the largest fens in Slovakia were found in the lowlands. What is left still harbours many characteristic species of fens and fen meadows, which means that these sites are somehow buffered against the very severe fen degradation that we encounter in most West-European countries.
The aim of the present study was to explore the prospects for restoration of several calcareous spring mires in Slovakia that have been damaged by man made changes in the hydrology or lack of management. The research was carried out in two well preserved calcareous spring mires in the Northern part of Slovakia. The Nature Reserves Belianske lúky and Štrba represent fine examples of little disturbed spring mires Slovakia. We carried out an ecohydrological analysis for the areas to evaluate the hydrological functioning of the mires and the ecological responses to changes in their hydrology. We also studied nutrient limitation for the vegetation and longevity of soil seed banks in some selected sites. With this research we aim to assist in developing adequate restoration plans for these highly endangered fen systems.

Key words: Caricion davallianae, groundwater, hydrology, peat development, seed bank, spring mires, travertine.

Introduction

Calcareous spring mires; defining the ecosystem

A calcareous spring mire is a peat forming ecosystem that is fed by calcareous groundwater and that is regularly depositing travertine (calcite) on the surface of the mire. In most mire typologies these mires belong to the rich fens, in which the word rich refers to richness in dissolved minerals, not to species richness or nutrient availability (see for an overview JOOSTEN & CLARK 2002). The nutrient availability in calcareous fens is very low, but its biodiversity is usually very high. Calcareous fens are critically endangered in most of Europe. In Slovakia they may harbour critically endangered plant communities such as the Caricion davallianae, with species such as, *Primula farinosa*, *Pedicularis sceptrum-carolinum*, *Epipactis palustris*, *Pinguicula vulgaris*, and *Utricularia minor*. Calcareous fens belong to the so called coldland communities (TALLIS 1991). They are largely a Pleistocene creation and have existed in the northern part of Eurasia and their mountain areas since c. 10.000 years. This relationship with cold conditions is clearly illustrated by distribution maps of some of their most typical plant species. *Pedicularis sceptrum-carolinum* (Fig. 1), for instance, is a species with a northern distribution but also occurs in mountain areas in western and central Europe (TYLER 1981, DIERSSEN 1996). *Primula farinosa* has its main distribution in Northern-Russia, the Baltic States, South-Sweden and also occurs in European mountain areas.

Calcareous fens are situated in river valleys, fed by large hydrological systems, near geological faults where clay layers have shifted and where cold groundwater from relatively large aquifers is discharging, but also on calcareous substrates, which have been exposed after lowering lake levels (JASNOWSKI & KOWALSKI 1978). Slovakia can be

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Fig. 1: *Pedicularis sceptrum-carolinum* at Belianske lúky (photo J. RIPKA)

regarded as a peripheral area of coldland communities. More to the south and in low lying areas they become less frequent and the fens become more susceptible for hydrological and climatological changes. The remaining calcareous fens in Europe can be regarded as a refuge for very many endangered plant species that have nowhere to go, once the ecosystems they depend on are destroyed. In fact most calcareous fens in Europe cannot be considered real mires anymore, since they do not accumulate peat anymore. Most remnants have become fen meadows, which are regularly mown or grazed. A modest drainage of a fen does not necessarily lead to a decrease in biodiversity. STANOVA (2003), for instance, published an extensive study of the vegetation changes during the last 30 years in the Slovak fen meadow reserve Abrod (92 ha). She showed that since 1960 the reserve had been affected by drainage in the surrounding agricultural areas to such an extent that the original peat had been severely mineralized, leading to eutrophication and acidification in parts of the reserve. Yet the species list of the area had increased from 294 to 480. This area now provides a habitat for 104 species on the Slovak Red List, of which 3 only occur in Abrod: *Gladiolus palustris* (on the IUCN Red List), *Schoenus nigricans* and *Dactylorhiza ochroleuca*. In this chapter we will not make a sharp distinction between fens and fen meadows.

Decline of calcareous fens in Europe

Many protected fens and fen meadows are facing serious management problems, as traditional farming (mowing, grazing and cutting of trees and shrubs) is not profitable anymore. This serious lack of management and lack of understanding of the hydrological functioning of established nature reserves is very disturbing. The dominant nature conservation practice during the communist rule was to ban traditional management – i.e. haymaking and grazing- in all protected areas. During that time many so-called 'protected areas' have been partly drained just before they were designated as a protected area. Since then, the traditional management stopped, resulting in shrub and tree encroachment.

Present situation of calcareous fens in Slovakia

It is calculated that during historic times, peatlands in Slovakia were distributed over 260 km^2, which is 0.57 % of the total area of the country. At present only 25.8 km^2 of peatlands (less than 10%) are still remaining (STANOVÁ 2000). These figures demonstrate the dramatic decrease of peatland distribution. Of all peatland types, calcareous fens are under the strongest pressure. Prior to major drainage schemes, the largest fens in Slovakia were found in lowland Western Slovakia, with a total area of 4.506 ha. Most fens in that region have been drained, and changed into arable land. Rich calcareous fens are now almost exclusively restricted to the Carpathian Mountains; some remnants are still present in the lowlands. What is left still harbours many characteristic species of fens and fen meadows, which means that these sites are somehow buffered against the very severe fen degradation that we encounter in most West-European countries (KRATZ & PFADENHAUER 2001, VAN ANDEL & ARONDSON 2006). Most of these relatively small sites still represent good prospects for future fen regeneration and are of national importance. In Slovakia only few localities are

present where threatened species occurs in large numbers. One of them is called Poprad Meadows and is situated within the city limits of the town of Poprad. It was once a part of a large fen system that was later reclaimed for agriculture and which was also used as a peat cut area. Remnants of the fen were partly treated as a dump, but partly it remained a fen which harboured large numbers of endangered species. In the nineties the city of Poprad wanted to use the site of about 4.5 ha for building of new houses. Although the site itself was not protected by law, several plant species, however were protected. So an inventory was needed to estimate the value of the site from nature conservation point of view. MÁJOVSKY et al. (1990) found out, that the most important species occurring in large numbers were *Primula farinosa*, *Pinguicula vulgaris* and *Utricularia australis*. About 116 individuals of *Primula farinosa* per square meter were counted on 2 hectares of the site. In that time the fine for damaging one individual was about 14 . The total cost for destruction of the whole population was 325.769,– , which the city could not afford to pay and the development plans were cancelled.

Aim of the study in the Slovak fens

The aim of the present study is to explore the prospects for restoration of several calcareous spring mires in Slovakia that have been damaged by man made changes in the hydrology or lack of management. We carried out a ecohydrological analyses for the areas to evaluate the hydrological functioning of the mires and to ecological responses to changes in the hydrology. We also studied nutrient limitation for the vegetation and longevity of soil seed banks in some selected sites. With this research we aim to assist in developing adequate restoration plans for these highly endangered fen systems.

Description of the study areas

The research was carried out in two well preserved calcareous spring mires in the Northern part of Slovakia, very near the High Tatra Mountains (Fig. 2). The smallest spring mire is situated near the village of Štrba, while the second is a large spring fed fen near Spišská Belá and is called Belianske lúky.

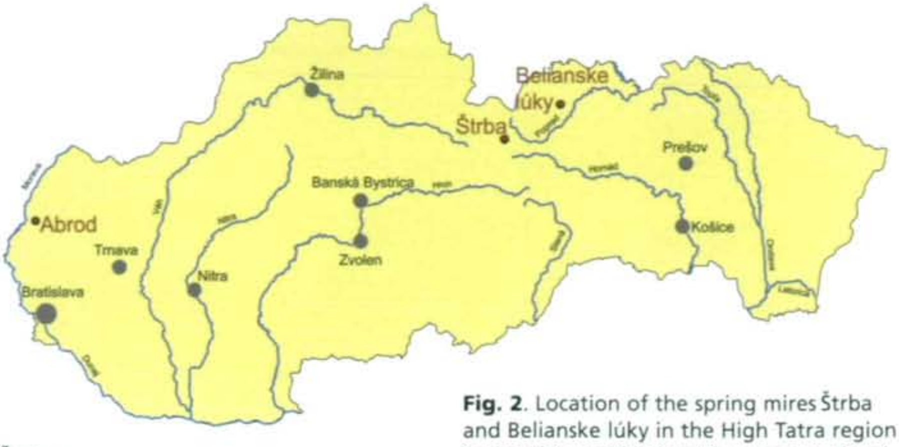


Fig. 2. Location of the spring mires Štrba and Belianske lúky in the High Tatra region in Slovakia and lowland fen reserve Abrod.

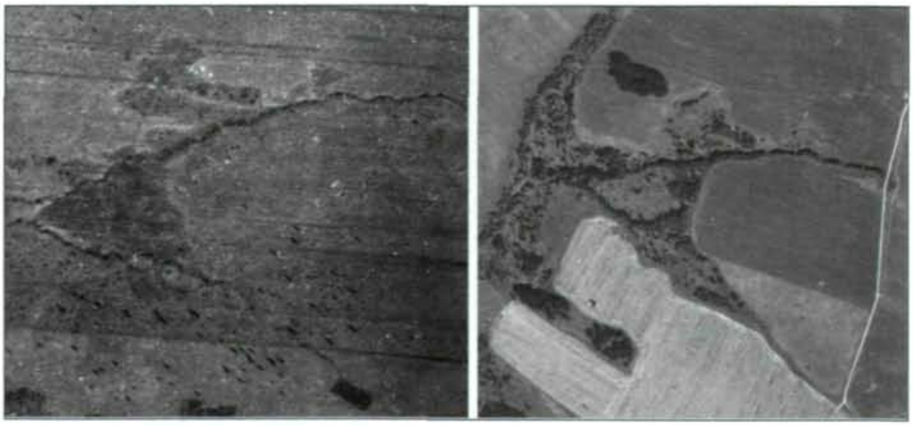
Štrba

This dome shaped mire of about 2 hectares near the village of Štrba is locally called "Pastierske 2" and it is not protected so far. It is a very well developed ground water fed fen system located in the Liptovská kotlina Basin. The project for the designation of nature reserve on the site has already been prepared. We will further call this mire 'Štrba'. Due to lack of management the shrubs and trees invade the site (Fig. 3). Recently the most important parts of the mire have been mowed again.

The mire is situated at a geological fault from which calcareous groundwater enters the mire via some cold springs (Fig. 4.). The site is not directly influenced by drainage, but the two streams on either side are quite erosive, due to storm floods that sometimes occur during very heavy rain. The mire consists of spring fens, small pools, wet and mesophilous meadows vegetation, and shrub communities (mostly *Salix* species).

The Štrba mire is only the fourth recent locality where the moss species *Calliergon trifarium* (category E-endangered) is still

Fig. 3: Aerial photographs of 1949 and 1997 showing the spring mire of Štrba between two small rivulets. The encroachment of shrubs and trees is evident, indicating changes in landscape use. (©: Eurosense Bratislava and Topographical Institute Banská Bystrica.)



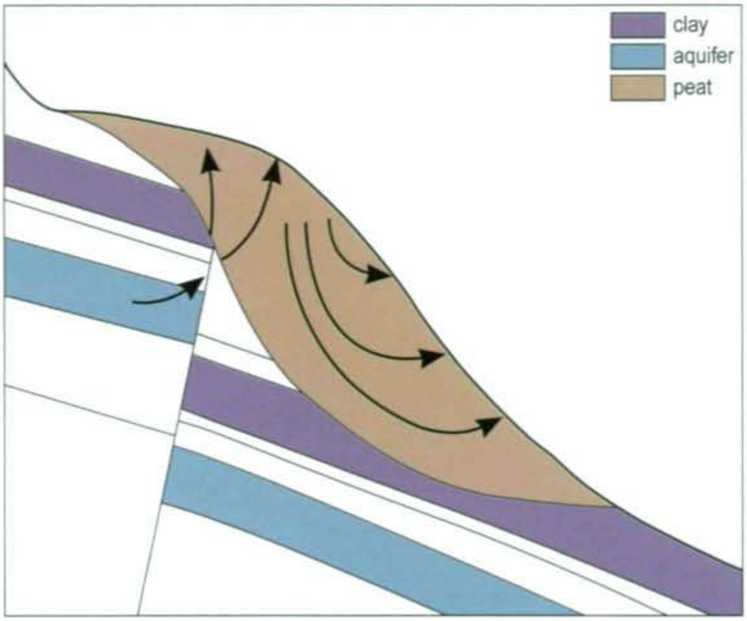


Fig. 4: Simplified sketch of the hydrological regime of the spring mire near Štrba. The groundwater flow in the water transporting layer (aquifer) is obstructed by the geological fault and is forced to the surface. This eventually has led to the development of the spring mire.

present. This species is considered a glacial relic in Slovakia. Also the moss species *Tomenthypnum nitens*, which is evaluated as a vulnerable species (V) occurs on the site and it is typical species for alkaline fens.

Belianske lúky

Belianske lúky is a Nature Reserve, which is the highest level of protection in Slovakia. The reserve is about 100 hectare in size and it is the largest and best-preserved spring-fed fen in Slovakia. The presence of many rare plant species, and plant communities, makes the area of high ecological value. Belianske lúky is located at the base of the High Tatra Mountains on the slope of the river Bela and consists of several terraces, which were formed as a result of erosion of the river Bela and other streams that are no longer visible in the field. At present the river Bela has cut 3 to 4 m deep into the youngest terrace and finally reached the bedrock.

The climate of the region is moderately warm and wet, with cold winters. The annual precipitation (rain + snow) is about 1.000 mm annually (900 mm Kežmarok and 1.500 mm Ždiar, DANKO et al. 2002). The area has been under human influence since a long time. In 1964 three swords from the Bronze Age (more than 1.000 BC) were found during peat digging in the Krivy kut mire (located about 2 km downstream from Belianske lúky). Much earlier, in 1891, two bronze vases, three axes and many other artefacts from the same period were found in the same site (DVORAK 2002). Already in 1271 people where living in Spišská Belá, which is close to Belianske lúky. Later from the 13[th] to the 16[th] century German settlers moved into the area, and used the area for grazing of cattle, the dryer parts were used for mowing. After their departure in 1945 the inhabitants of Lendak, working for cooperative farms, used the area until 1980. The area has been protected since 1967, when it was included into a buffer zone of the High Tatra mountain National Park. In 1983 it became a Nature Reserve. After the fall of the communist government at the end of the eighties the reserve has not been properly managed or used as result of unclear ownership. Part of the area is still not protected. The area is an interesting area because of its size and the fact that it has

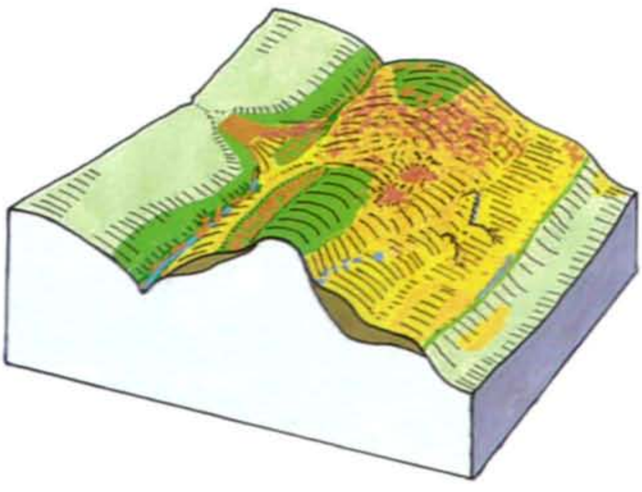


Fig. 5: Aerial photograph (© Topographical Institute Banská Bystrica) of Belianske lúky of 1997, showing some (dark) areas with much shrubs and trees encroachment. The sketch on the right shows peat deposits on either site of a mineral hill. The fens and fen meadows (yellow) are wrapped around this hill, while the hill itself and the valley flanks are cover with species rich hay meadows (green). Shrubs and trees (brown) are most abundant where the peat has been degraded due to lowered groundwater tables.

	1	2	3	4	5	6	7	8	9	10	11	12
	E	D	D	C	C	B	C	A	B	D	A	E
Carex paniculata	+	+	3	+	+		+	4			3	+
Eleocharis quinquaeflora						3		2b				
Primula farinosa		+		2b	2b	1	3		1	+		
Carex davalliana		1		3	5	5	4		3	2a		
Drepanocladus cossonii		4	5	3			2b		2a	4		
Homalothecium nitens	+	2a	2a	1	+		+		+	1		1
Valeriana simplicifolia				+	+	2a	1		+	+		
Alnus incana	3											3

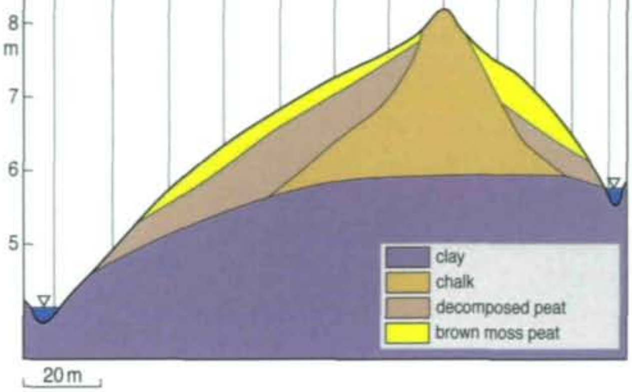


Fig. 6: Occurrence of vegetation types along a cross-section of the Štrba mire. Also shown are peat layers and the deposits of travertine.
A = Caricetum paniculatae WANGERIN ex v. ROCHOW 1951
B = Eleocharitetum paucifloraee LÜDI 1921
C = Caricetum davallianae DUTOIT ex KOCH 1928
D = Valeriano simplicifoliae-Caricetum flavae PAWLOWSKI et al. 1960
E = Alnetum incanae LÜDI 1921

been so well preserved, even after 10 years of abandonment. The main problem in the area is the rapid encroachment of shrubs, trees and reeds, due to lack of traditional management by mowing (Fig. 5). The hydrology of the spring system has also been influenced by upstream drainage systems.

Vegetation

Štrba

The fen communities belong to the alliance Caricion davallianae, and are dominated by small sedges like *Carex davalliana*, *C. lepidocarpa*, and *C. panicea*. Fig. 6 presents the vegetation zonation along a transverse transect set across the Štrba mire. The five distinguished plant communities (nomenclature according to VALACHOVIŽ 2001) are distributed in an almost symmetrical manner, showing a spatial correlation with topographical and hydrological features of the mire.

Vegetation type A is associated with concentrated spring outflows at the top of the mire. This community is dominated by large tussocks of *Carex paniculata*, but at the soil surface typical spring species occur, such as *Cratoneuron commutatum*, which actively participate in travertine formation. Such communities with dominance of *Carex paniculata* and fen species (not tall-sedge species) were described from Liptovská kotlina Basin within Caricion davallianae (OŤAHELOVÁ et al. 2001). Vegetation types B and C form a zone of small sedge communities that is rich in brown-mosses, surrounding the active spring mounds and forming the mire expanse. The vegetation consists of a well developed moss-carpet and belongs to the *Caricetum davallianae* association. They form a spatial mosaic with small, open water pools, with (with *Chara fragilis*), and with pool-side vegetation (type B - Eleocharitetum pauciflorae). The Štrba mire harbors many red-list species: *Primula farinosa*, *Parnassia palustris*, and *Pinguicula vulgaris*, and is particularly rich in orchid species: *Dactylorhiza incarnata* subsp. *incarnata*, *Dactylorhiza incarnata* subsp. *pulchella*, *D. majalis*, *D. lapponica*, *Epipactis palustris* and *Gymnadenia densiflora* (DÍTĚ & VLČKO 2000). Typical species of fen meadows (Molinion) and wet meadows (Calthion) are more frequent at lower ranges of the sloping fen. The typical association of this zone is Valeriano simplicifoliae-Caricetum flavae (vegetation type D), which has its main distribution in sub-mountain and mountain zones of the Western and Eastern Carpathians HAJEK & HABEROVA (2001).

In our case we see a successional tendency towards slightly more acidic moss communities (alliance Sphagno warnstorfiani-Tomenthypnion) dominated by *Homalothecium nitens*. Vegetation type E represents a vegetation complex, which is associ-

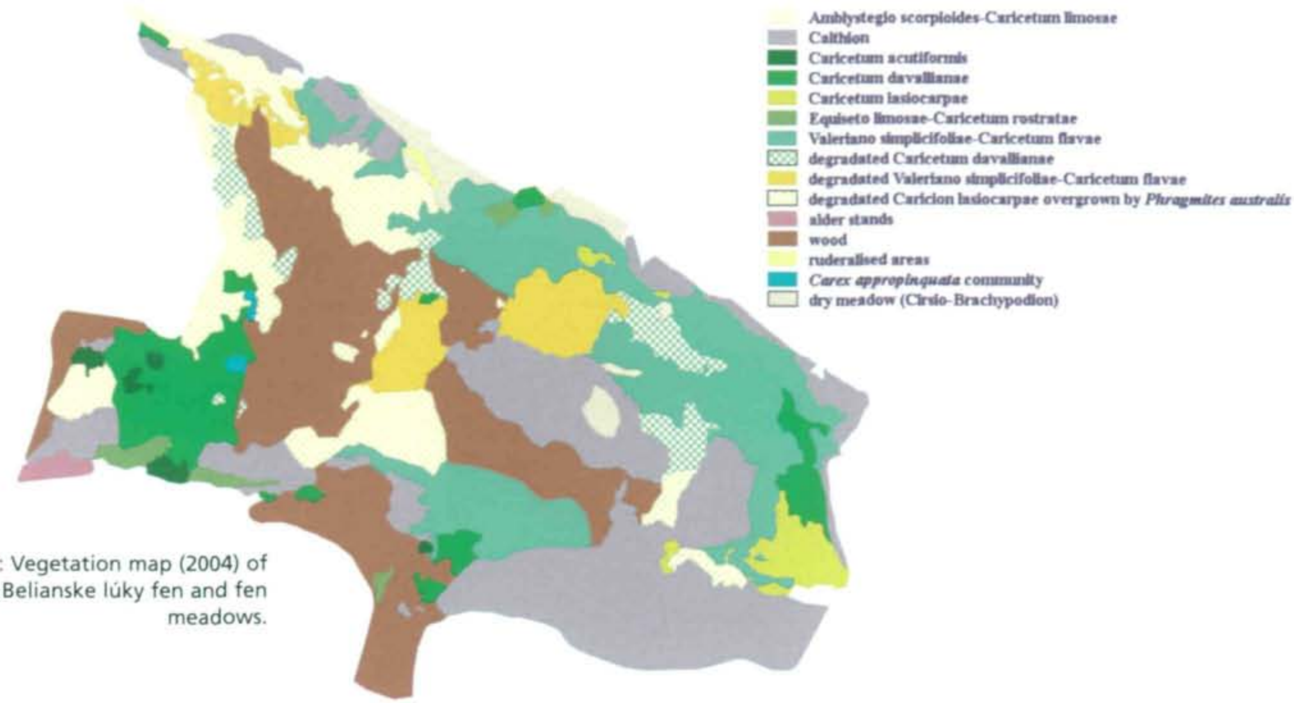


Fig. 7: Vegetation map (2004) of the Belianske lúky fen and fen meadows.

ated with streams flowing in erosion gullies at the outskirts of the mire. This vegetation contains ligneous species, such as grey alder - *Alnus incana*, willows and other shrubs, as well as several tall forbs and herbs. It also hosts a large number of rare and interesting species, such as *Trollius europeus* and *Cardamine amara*, thus adding to large biodiversity of the Štrba mire.

Belianske lúky

Rare and endangered plant communities that are found in Belianske lúky are Caricetum davallianae and Caricetum diandrae Jonas 1933. HAJEK & HABEROVA (2001) and DÍTĚ & PUKAJOVÁ (2002) described a rare association (Amblystegio scorpioidis-Caricetum limosae Osvald 1923) from the site with the occurrence of a critically threatened species (*Carex limosa)*, that normally occurs in acid bogs, but here is found in a calcareous fen vegetation. This is a very rare phenomenon in Central Europe. Belianske lúky also harbours the largest population of *Carex limosa* in Slovakia. Furthermore, the area is very rich in orchids like *Dactylorhiza incarnata*, *Epipactis palustris* and the critically endangered *Dactylorhiza lapponica*. Other red list species are *Primula farinosa*, *Carex limosa*, *C. dioica*, *Iris sibirica* and *Pedicularis sceptrum-carolinum*. The latter species is present with several large populations of flowering plants and could represent the most viable population in this part of Europe.

Moss species are also abundant. So far 10 red listed species have been found on the locality by ŠMARDA (1961) and ŠOLTÉS & NOVÁK (1999). Three of them, *Calliergon trifarium*, *Meesia triquetra*, *Drepanocladus lycopodioides* are evaluated as endangered species (E). *Calliergon trifarium* and *Meesia triquetra* are very rare glacial relics indicating well-preserved fen ecosystems. They occur only in a few localities in Slovakia (ŠOLTÉS & NOVÁK 1999). Belianske lúky is, therefore, one of the most important reserves for threatened moss species in Slovakia.

A recent vegetation map of Belianske lúky (Fig. 7) shows that about half of the vegetation consists of well developed Calthion palustris and Caricion davallianae communities, each having about an equal share. The other half consist of degraded fen meadow (Caricion davallianae) types and forest types. The most abundant vegetation type is a species-rich meadow vegetation (Calthion palustris) dominated by *Cirsium rivularis*, *Polygonum bistorta* and sometimes *Trollius europeaus*. This type is primarily found on clayey mineral soil with an organic layer of less than 10cm (Fig. 8). It occurs on top of the mineral hill and along flanks of the terraces on which little or no peat was

formed (see also Fig. 5). The fen and fen meadows include relatively moist vegetation types dominated by *Carex davalliana*, *C. lepidocarpa*, wet types dominated by *Carex rostrata* and *Menyanthes trifoliata* and pools with *Drepanocladus cossonii* and *Eleocharis quinqueflora*. In these vegetation types most of the red list species occur: *Primula farinosa*, *Pedicularis sceptrum-carolinum*, *Swertia perennis*, *Pinguicula vulgaris*, *Carex limosa*, *C. dioica* and *Drosera rotundifolia*. The fens and fen meadows occur where peat layers of more than 80 cm have been formed (Fig. 9). Slight degradation of these types may be observed by invasion of grasses *Molinia caerulea* and *Calamagrostis* sp. At some places transition stages between the *Caricion davallianae* and the *Calthion palustris* meadows are present. These transition stages seem to occur were thin peat layers, mostly near the top of the mineral hill, are present.

Degraded *Caricion davallianae* types, with much *Phragmites australis*, and forest types, with *Alnus glutinosa*, *Pinus sylvestris* and *Betula carpatica*), cover almost 40% of the area, indicating lack of management since 1980. The encroachment of trees is most evident at places where old drainage systems are present or where the peat has been dried out due to drainage activities in the past.

Peat development

Štrba

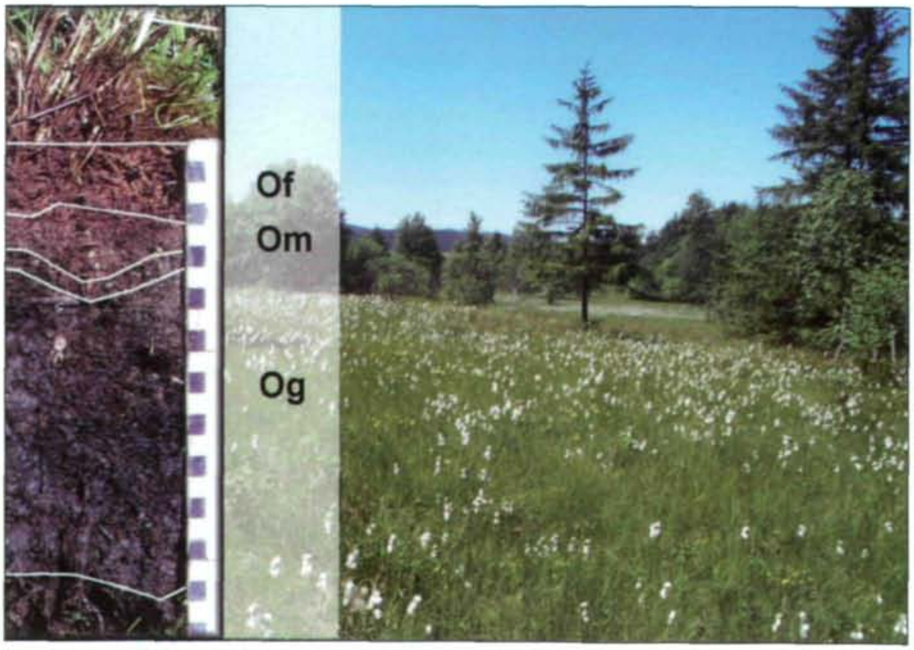
The development of the spring mire Štrba started with depositing large amounts of travertine, almost without any peat formation. The maximum thickness of the travertine layer was about 1 m (Fig. 10). In a later stage peat was formed and the travertine was mixed with much organic material.

At a certain stage, the travertine formation stopped. Peat was formed without any $CaCO_3$. In most of the profile this peat was severely mineralized and compacted. On top of this a less mineralized peat was formed over the entire mire. Then suddenly travertine formation started again in the centre of the mire and formed a thin layer down slope (see also Fig. 11). We have at present no information about the climatological and hydrological conditions in which these deposits have been formed.

Some profiles were analysed microscopically and the results (Tab. 1) showed clear layers of brown moss peat (mostly *Drepanocladus cossonii*), which were followed or preceded by travertine deposits, sometimes with much small sedge peat. These results clearly point to stages of (nutrient-poor) peat formation, which were followed by (wetter) stages in which travertine had been deposited in shallow pools or due to surface water flooding the peat.

Fig. 8: Wet meadow vegetation (Calthion palustris) with *Cirsium rivulare*, *Crepis paludosa*, and *Equisetum fluviatile* on a shallow decomposed peat layer (Oh). Further down an iron-rich, humic mineral layer is present on top of a clayey soil type with sometimes large stones in it and also much iron. (Photo Bas van Delft)

Fig. 9: Fen vegetation (Caricion davallianae) dominated by small sedges and Eriophorum latifolium. The soil profile consists of a well preserved (fibric) top layer followed by a slightly decomposed peat. The black peat is decomposed under anaerobic condition and contains much ironsulphide. Each square is 1 cm. (Photo Bas van Delft)



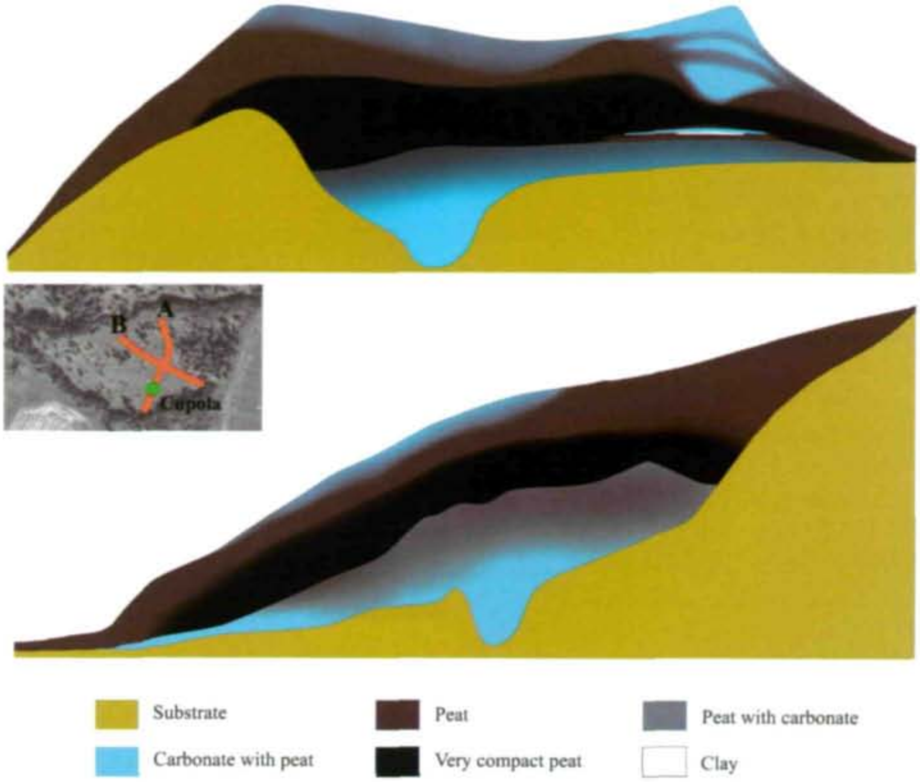


Fig. 10: Travertine (terrestrial chalk) deposition and peat development in the spring mire near Štrba. The system started as a mineral spring that deposited almost pure travertine. In a later stage almost pure peat covered the spring. Travertine formation started again in the last stage of mire development.

Belianske lúky

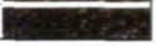
We have described eight transects in the Belianske lúky mire and they showed that the peat development was very variable in space and time. At some places we found lake deposits and *Phragmites* reeds, while at other sites the vegetation started as an alder forest. All profiles showed very well preserved peats, but sometimes very degraded peats were found as well, indicated ether dry periods or changes in the local hydrology. The mire has always been very diverse and consisted mainly of small sedges, brown mosses but also at various sites of small bogs dominated by *Sphagnum* species. Travertine formation has started in a rather late stage of the development of the mire and the amount of travertine is modest compared to Štrba. At some selected sites we made detailed macrorests descriptions. Tab. 2 illustrates the details of one profile, which need not be representative of the mire development at Belianske lúky.

Fig. 11: Soil profile in the pool system of Štrba showing travertine deposition on top of the peat. At the right travertine deposition at the surface can be seen as well as precipitation of ironhydroxide. (Photo M. Madaras)

Tab. 1: Detailed analysis of macro-rests, using a microscope, showing distinct layers of brown moss peat and travertine in the spring mire Štrba.

Depth cm	Components (%)	$CaCO_3$ (%)	Type of substrate	
0-4	*Drepanocladus cossonii* 85; 10; precipitates Ca+Fe)	37	Brown moss peat	
5-8	Travertine >50; brown moss 40 (*Drepanocladus cossonii, Bryum sp.*); sedges 10	55	Travertine with brown moss peat	
9-12	*Drepanocladus cossonii* slightly decomposed 70; small sedge 20; minerals (Ca) 5	51	Brown moss peat	
12-20	Travertine >50; small sedge 25; brown moss 5;	49	Travertine with sedge peat	
20-30	Travertine >50; small sedge 25; brown moss 20 (*Drepanocladus cossonii*); other (detritus) 5	49	Travertine with small sedge-brown moss peat	
40	Travertine >50; brown moss 40; small sedge 5;	54	Travertine/ brown moss peat	
50	Highly decomposed peat from sedge-wood peat; brown moss 10; sedges 10; wood-decomposed 25;	1,5	Humic peat	

Tab. 2: Detailed analysis of macro-rest, using microscopes, showed that in deeper layer *Sphagnum* species dominated the vegetation. At a certain stage *Sphagnum fuscum* became dominant, a species that usually is restricted to acid bogs, fed by rainwater. In this case such vegetation types have developed in springs fed by groundwater. The photographs illustrate that the *Sphagnum* leaves have been preserved very well.

Depth (cm)	Components (%)	$CaCO_3$ (%)	Type of substrate	
0-10	Humic coagulate 80; mineral 5; brown moss leaves 1; detritus 1	1.3	pool mud?	
10-20	Small sedge 70; brown moss 20; humic coagulate 10	1.0	brown moss/small sedge peat	
20-80	Humic-mineral coagulate 70- 95; small sedge 5-10, Sphagnum and brown moss 5-10.	0.7	pool mud	
80-90	Brown moss 30; small sedge 25; *Sphagnum* 5; humic coagulate 30; mineral 10.	3.4	brown moss/small sedge peat	
90-130	*Sphagnum* 80-100, Brown moss 0-20.	1.7	Sphagnum peat	
130-140	***Sphagnum fuscum*** 100.	0	Sphagnum peat	
140-170	*Sphagnum* 80-95; sedges 2, brown moss 3;0 twigs of shrubs 8		Sphagnum peat	
170-180	*Sphagnum* 40; brown moss 30; *Thelypteris* fern 20	0	Sphagnum/brown moss peat	
180-240	*Sphagnum* 70-90; brown moss 3-20; sedges 5, detritus 2-10	0	Sphagnum peat	
240-250	Brown moss 30; Sphagnum 30; vascular plants 20; detritus 20	0	poor fen peat	
250-260	Charcoal !!; humic substance; sand		humic peat (sedge-wood?)	

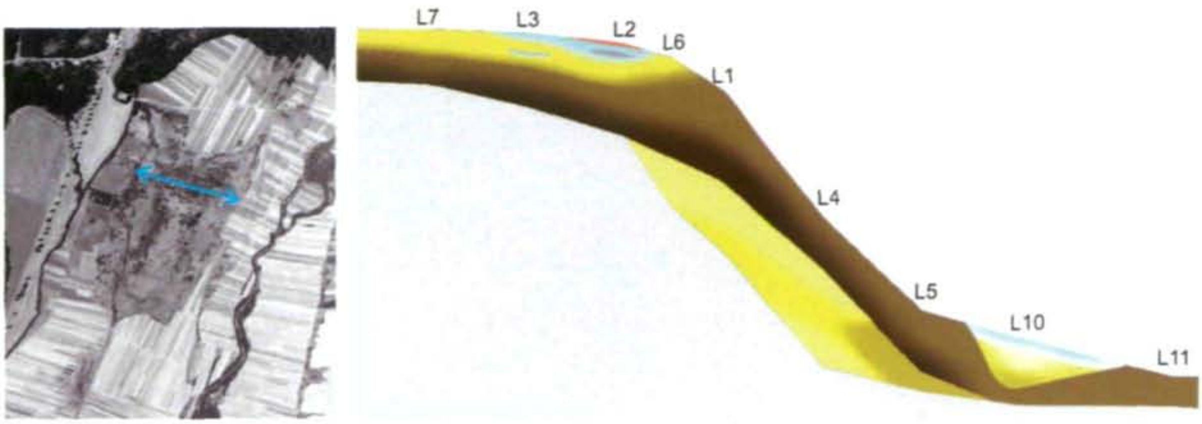


Fig. 12: Peat development in a cross-section of Belianske lúky, showing well preserved peats at the base with a low grade of decomposition (yellow). The peat layer is covered by a more decomposed layer of peat (dark brown). At certain spots new peat has been formed at the base and the top of the mire. Here we also find pools and travertine formation (blue).

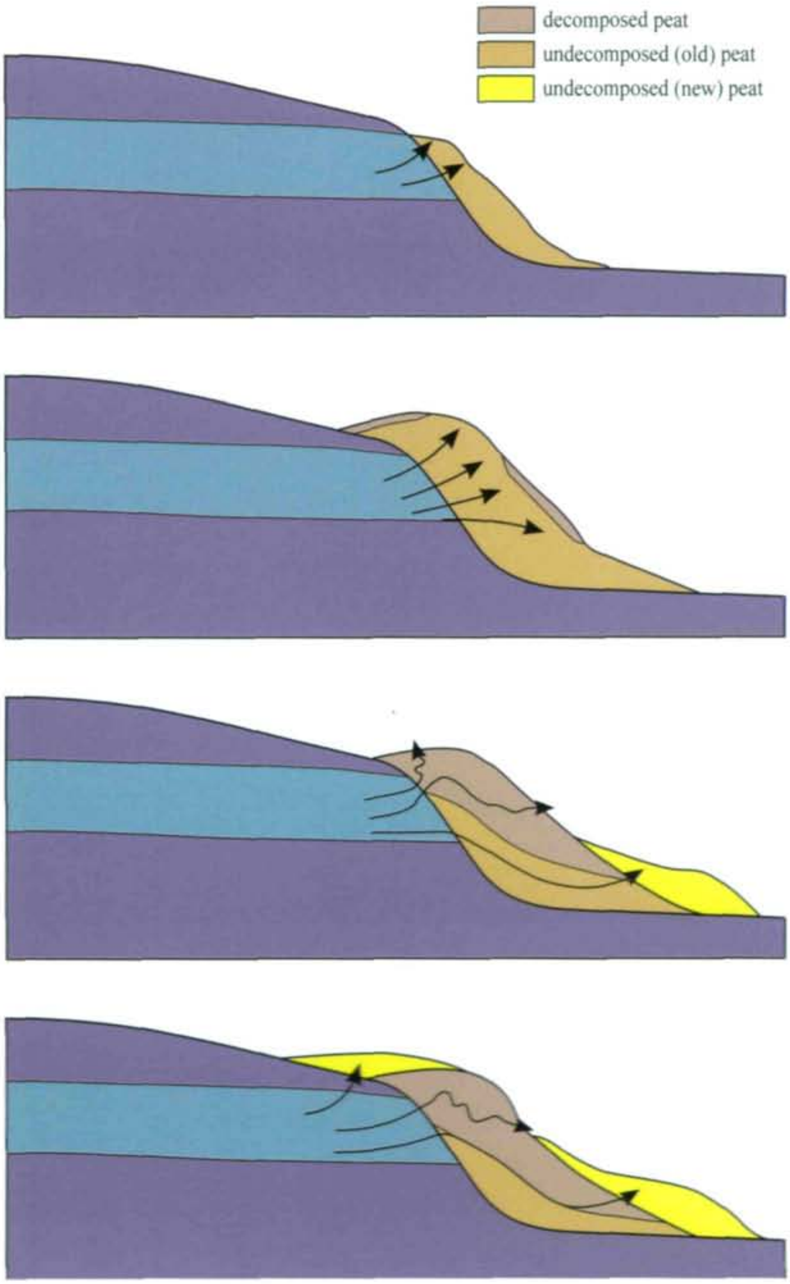


Fig. 12 illustrates the sequence of peat types in a transect across the western part of the mire. We see well preserved peat layers underneath much decomposed peat and at some sites well preserved peat are found on the decomposed peat. This could reflect wet and dry periods in geological periods, but there are clear deviations, which appear to be related to hydrological changes in the system. Based on such descriptions of peat stratigraphy we made an interpretation of the past peat development in this spring mire (Fig. 13). Again the sequence of peat types need not be representative for the mire as a whole. Severe desiccation of the peat did not occur in all transects.

Belianske lúky is fed by groundwater from a geological formation consisting of a mixture of fine and very course sediments, in which the groundwater can flow relatively well. Such a layer is called an aquifer. Underneath the aquifer and on top of it we find

Fig. 13: Reconstruction of the peat formation in Belianske lúky at the transect depicted in figure 12. We think peat formation started here with small mixed mires, consisting of brown moss and small sedge species, sometimes even dominated by real bog species (*Sphagna*). At a certain stage part of the peat was affected by severe drainage, due to some change in the hydrology. The compacted peat forced the groundwater to discharge lower down at the slope, where new peat was formed. Under wetter conditions peat formation also started again close to the top, where resistance to water flow was small. Pool formation was also stimulated at the end of the mire development.

clayey layers that permit only a modest flow of water. After the retreat of the glaciers in the Tatra Mountains, eroding rivers carved away much of the earlier sediments and exposed the aquifer from which groundwater escaped and spring vegetation developed in depressions all around the mineral hill. The discharge of groundwater must have been lower than today, since several small bogs have developed in Belianske lúky. They consisted of both sedges and *Sphagnum* species and could be called 'mixed mires' (HAJEK et al. 2002), which still can be found in mountain areas in Slovakia and the Czech Republic. Some transects show severe decomposition of the peat, indicating water stress. Apparently a drastic change in the hydrology must have taken place. Very decomposed peat has a high resistance to water flow and this dried out peat at the upper parts of the spring mire becomes a blockade. The water will have to find new flow paths through the mire. The easiest way is a short cut to lower areas. Often such a new transport route through desiccated peat is very erosive and forms small tunnels, to finally leaving the mire through a small rivulet (Fig. 14). At present two such erosive rivulets are present in Belianske lúky and they originate from sites with very degraded peat on top. Another way out for groundwater under pressure is very close to the top of the hill, where the overlying clay layer is very thin. New peat appears to have been formed both close to the top and below the slope.

The building of drainage works above the spring mire started in 1964. This drainage system directly borders the site on the northwest side and consists of drains, which are 10-11 m apart and placed at a depth of 90 cm. The desiccation could be triggered by climatological changes, but it is more likely that human activities, such as digging drainage ditches were responsible for the degradation of several parts of the spring mire.

Fig. 14: One of two erosive rivulets in Belianske lúky, which originate from sites with very degraded peat on top (Photo V. STANOVÁ)

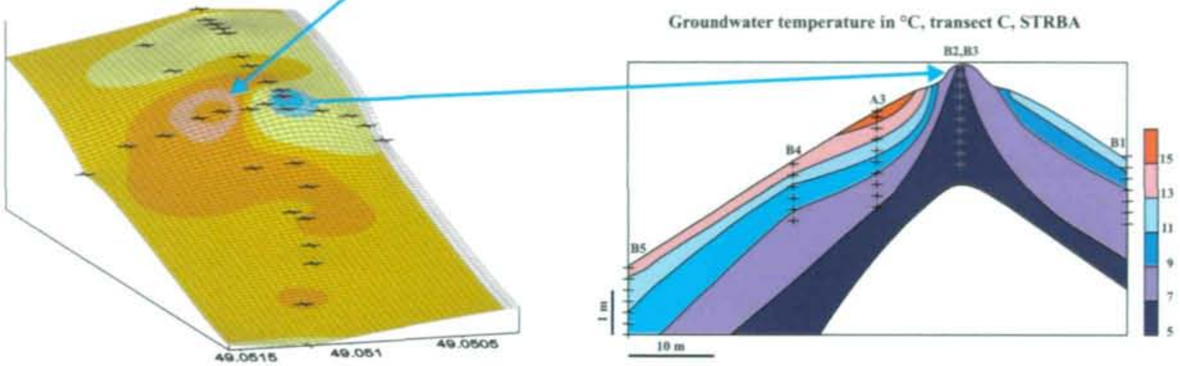
Hydrological systems

Štrba

We studied the groundwater flow patterns of Štrba mainly by measuring temperatures in the soil along several transects. Water temperature is usually a very good indicator of origin of the groundwater. Groundwater that is very cold in summer must come from very deep layers, which are not affected by the increase in temperature during the summer. Warm water most likely originates from local sources close to the surface, or it is warmed in small pools as surface water.

Fig. 15 shows a temperature profile (to the right), where we can clearly see that cold water is discharging in the centre, and gets warmed up in the pools (to the left in Fig. 15). Than the warm water infiltrates back into the mire slightly lower at the slope. The surface temperature of the pools increases within the pools (inflow vs. outflow) as well as going down hill. This temperature profile indicates a direct influence of the cascade of pools on the groundwater

Fig. 15: The photograph shows a pattern of very thin layers of iron bacteria (blue colours) following the flow direction in the surface water in a pool. Such iron bacteria live of the ironhydroxides that have been precipitated when the discharging groundwater is coming to the surface in the pools. The discharging groundwater originates from a cold spring. In the pool itself the surface water is warmed up during the summer. (Photo A. Grootjans)



temperature. The warming of groundwater seems clearly stimulated by the presence of pools and this increase in temperature is relevant for the precipitation of chalk. In and along the pools a lot of precipitated $CaCO_3$ can be found. Cold groundwater from deeper layers usually has high concentrations of CO_2. The warming of groundwater, which is saturated with calcium and bicarbonate stimulates the escape of CO_2 to the air. This is called 'outgassing' (DRAMIS et al. 1999). When CO_2 escapes to the air the calcium and bicarbonate cannot longer remain in solution and precipitate as travertine. If the water flow in the pool is very slow, than the travertine is precipitating in the pool or on the surface of the mire when surface water is flooding the mire when it leaves the pool. When the water flow is rapid, the water temperature remains very low for a considerable time and outgassing occurs when the water has reached low-lying areas, such as lakes downstream. So severe erosion in a spring mire leading to fast flowing water leaving the springs, results in formation of travertine far away of the spring mire, thus preventing a new supply of chalk that can buffer the mire against acidification and that keeps the nutrient levels in the peat at a low level.

Belianske lúky

The hydrology of the large spring mire Belianske lúky is much more complex than that of the small spring mire near Štrba, which receives artesian groundwater from a blocked aquifer in a geological fault. Belianske lúky receives groundwater from a larger aquifer that has been exposed to the surface by erosion of rivers. The water discharges from a mineral hill at very many places.

Fig. 16 shows that cold water is discharging predominantly at the lower end of the spring mire. In mid summer the water temperature is less than 6° C, while the air temperature can be above 25° C. At the left end side of Fig. 15 we see that very cold water discharges in a small hole, where the temperature of the water is always about 6° C, but where no travertine formation was observed. Further upslope less cold groundwater is surfacing too (yellow colour). This site appears to be a former spring, where at present no water is coming out, but where the abundant growth of *Equisetum fluviatile* indicates the presence of anaerobic groundwater. A possible interpretation of these temperature profiles is that due to drainage activities at the down slope agricultural areas, the spring has shifted to lower areas. Warm water spots can

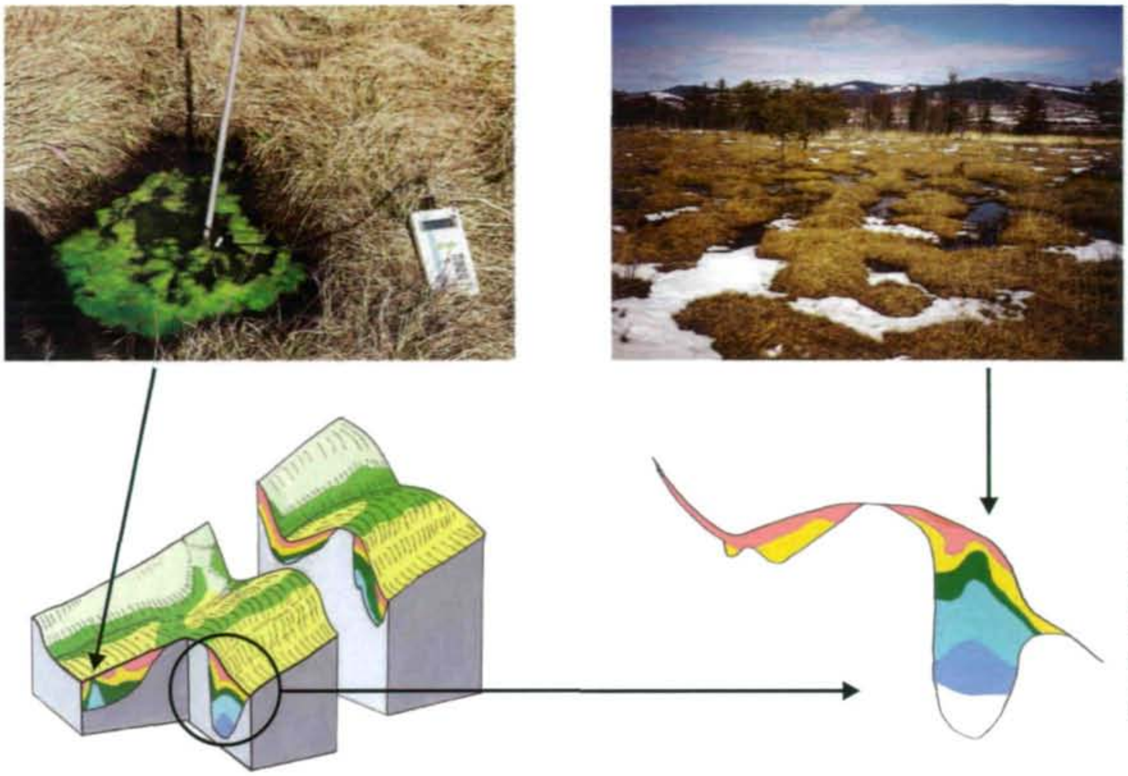


Fig. 16: Temperature profiles in some cross sections of the spring mire Belianske lúky showing discharging cold water (blue) and infiltrating warm water (red). The left photograph shows a very cold spring where temperatures are always 6-7° C. Local farmers have also found the spring and sometimes use it to store beer bottles during a hot summer. The photograph on the right shows a complex of pools near the top of the spring mire, which are unfrozen during the winter, indicating relatively warm discharging groundwater. (Photos M. MADARAS)

be found in the upper part of the profile and appear to be the result of a cascade of pools where groundwater is warmed up when surfacing in the small pools. A closer look of Fig. 16 shows that the cold discharging groundwater is flowing upward and appears to prevent the warmed up surface water from the pools to rapidly infiltrate to deeper layers. The warm water thus is forced to slowly follow the peat layer close to the surface, where it can precipitate travertine (if it originate from groundwater), or dissolve it again (if it originates from rainwater). After a heavy rain during the summer of 2003, we indeed found very calcareous groundwater underneath the steep slope of the mire (compare ALMENDINGER & LEETE 1998).

A similar patter can be observed in Fig. 17. Here also warming up of groundwater underneath the pools can be observed, but the influence of cold discharging groundwater is much less. This profile was measured in 2003, which was an extremely dry year and consequently little groundwater discharged from the aquifer.

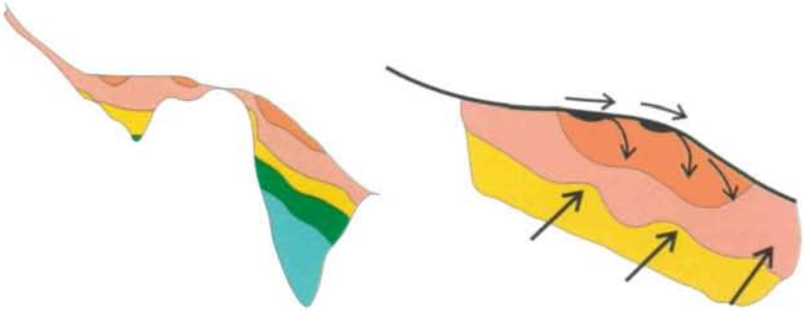


Fig. 17: Temperature profiles in a transect across Belianske lúky, showing high temperatures at the surface and low temperature below. Temperatures are high below the small pools, where surface water is warmed up and then infiltrates again down slope.

Synthesis

From our research is has become evident that calcareous spring mires are dependent on a regular discharge of (supersaturated) groundwater that prevents soil acidification and keeps the availability of nutrients at the low level, thus slowing down grass, shrub and tree encroachment. This groundwater is normally very cold and does to exceed 6-7° C, when discharging from the groundwater aquifer. The term coldland communities (TALLIS 1991) for mires with a northern and alpine distribution, is well chosen. A regular discharge of cold calcareous groundwater is an absolute requirement for these communities. It also implies that the surrounding catchment area that supplies the mire with

groundwater should be part of a protection plan. Just preserving coldland communities within the boundary of their occurrence is not a sustainable solution to nature protection.

The Nature Reserves Belianske lúky and Štrba represent fine examples of little disturbed spring mires Slovakia and compared to similar systems in other mountain areas, they can be regarded as jewels in the crown of the mire kingdom. Štrba is very small, but is hydrologically least disturbed. Belianske lúky shows clear signs of hydrological disturbances. Both mires have a rich history. Štrba started as a spring system that deposited almost pure travertine directly on the surface. It has been a 'petrifying' spring for centuries. In a later stage it became a mire and the travertine was covered with peat. This is a nice example how springs can become mires, in this case it has many characteristics of a 'percolation mire', where groundwater is slowly flowing through the top layers of the mire. The present vegetation shows marked resemblance of peat forming vegetation in the large river valleys in the lowlands of eastern Germany some 3.000-5.000 years ago (MICHAELIS 2002). At the moment small parts of the mire are (again) depositing travertine on top of the peat and in the small pools that have been formed down slope of the main spring. Belianske lúky was once a conglomerate of very different mire systems. There were very wet forests, reeds, small fens and even bogs. The bogs were dominated by *Sphagnum* species. Bog formation started at one spot on top of a charcoal layer. Apparently the forest was burned. Such bogs were clearly associated with sedge species and basiphilous herbs, indicating that the mire was not only fed by precipitation water, but also by groundwater. Such small spring mires still exist elsewhere in Slovakia and Eastern Czech Republic (HAJKOVA & HAJEK 2003). At a certain stage even a 'true bog' species was found in the peat of Belianske lúky (*Sphagnum fuscum*), which is generally regarded as a species that is exclusively found on very acid bogs. This may be so in the large bogs of the European lowlands, but the situation may have been different in mountain areas. RYBNICEK (1974) mentions the occurrence of *Sphagnum fuscum* in calcareous fens in the Central part of the Czech Republic, so apparently very acid conditions can exist within a larger groundwater fed system. He describes a whole series of spring mire communities that are dominated by *Sphagnum* species In some communities basiphilous species, such as *Eriophorum latifolium*, *Epipactis palustris*, and *Carex appropinquata*, are also frequent. This is the Sphagno warnstorfiani-Tomenthypnion Dahl 1957, which represents fen communities with calci-tolerant *Sphagnum* species. The water level fluctuations, measured in 1961 from April to November, in these mires appeared to be remarkably low (less than 10cm). The groundwater is between 5 and 15 cm below the surface and in the most basiphilous types no flooding occurs. Rybnicek presents even a photograph of the basiphilous community with *Sphagnum fuscum*, from which it is evident that this 'bog' species is growing in a mixed mire; herbs and sedges of fens grow together in the *Sphagnum* carpet. This all points to a very stable groundwater level, where the calcareous groundwater almost never reaches the top layer (Ca concentrations in the pore water are always lower than (20 mg/l). Recent research (LAMERS et al. 1999) has shown that most *Sphagnum* species can grow well at low concentrations of HCO_3. Concentrations above 2 meq/l HCO_3 are toxic to most *Sphagnum* species. Based on the Ca concentrations and pH values presented by Rybnicek (between 5 and 6), we estimate that the HCO_3 concentrations were always below 1 meq/l. in the top layer. This explains why 'acidophilous' species can co-exist with basiphilous species, which partly are rooting in lower parts of the peat.

We know little about the hydrological and ecological conditions in the time that the Belianske lúky mire was still young. We found remnants of wetland forests, reeds, small lakes and fens. The mixed mires appeared later and they were initially not flooded with calcareous groundwater, because that would have stopped the formation of *Sphagnum* peat. So we may presume that the groundwater discharge was not very intensive. In a later stage the mire started to precipitate travertine in the top layer of the sloping parts of the fen. The formation of a true percolation mire with groundwater flowing through the top layers of the peat

probably began in a period with more precipitation or after a period with intense felling of woods by humans, leading to increased groundwater flow in the spring area. We have signs of repeated degradation of the peat, leading to very decomposed organic layers. But every time the mires recovered somehow and started to form new peat. The most devastating peat degradation is probably quite recent and is could be triggered by the digging of ditches in the low lying areas. May be this was done by farmers to transform the peat forming vegetation into meadow vegetation, which has higher yields. Future palynological research might shed more light on this hypothesis. Anyway, drainage was only partly successful and led to an enormous variety of plant and animal species in the meadows that have survived until the present day. At sites with a very steep slope hydrological changes, either climate driven are due to human activities, triggered a concentrated outburst of groundwater at the base of the mire, leading to small erosive streams and desiccating the peat on top of the hill. When the mowing stopped, these sites were rapidly overgrown by trees. But there are also clear sign of recovery. The two erosive rivulets, for instance, flow into very wet peat forming vegetation at the periphery of the mire, where the surface water is dispersed and completely disappears into the mire.

We have studied several aspects of spring mire ecology in Slovakia between 2001 and 2004 and we have not solved the whole puzzle. We found several drainage systems of very different age. The former rivulet through Belianske lúky has been diverted and only remnants of it can be traced in the field. The most recently installed drainage systems, installed in the communistic time, appear to have had some negative effect on the mire, but the older drainage systems within the reserve, probably have had a much larger impact. We have not yet been able to quantify these effects nor, can we date the older drainage systems exactly. We think that human interferences with the hydrology in recent times (several centuries ago) have triggered a more pronounced travertine deposition on the mire surface, but we know that also climatic changes can trigger such a phenomenon (DOBROWOLSKI et al. 2003). Some authors think that travertine deposition has occurred very often in time, but that most of it has been dissolved again by infiltrating rainwater (ALMENDINGER & LEETE 1998). What appears to be clear is that shifts in the local hydrological conditions are highly responsible for shifts in travertine deposition and that both peat formation and peat degradation reflect hydrological conditions. That is why hydrological conditions in the spring mires should not deteriorate further if we want to preserve the extremely high biodiversity of calcareous spring mires in the Slovak Republic.

The future of Slovak calcareous fens

The future of the remnants of the Slovak calcareous fen lies in mowing. In many areas regular mowing has stopped several decades ago. In some reserves mowing has been continued by volunteers, nature management or local governments in order to conserve the high biodiversity that is linked with these nutrient poor fen meadows. This biodiversity can remain for many years due to the very low nutrient conditions, which is sustained by a continuous supply of calcareous groundwater. Decrease of groundwater discharge in and around these fen meadows will accelerate the encroachment of tall grasses, shrubs and trees and this will enhance the decline of the protected species in the meadows considerably. That is why it is wise to create hydrological buffer zones around the reserves, in which all drainage systems are removed. But eventually regular mowing is required to maintain the biodiversity of these systems. We have observed that the fen vegetation with many rare and endangered species can maintain itself without mowing for several decades. Then trees take over and most populations of light loving species decline. They also cannot compete with fast growing herbs and grasses. Several of such species do not form long-lived seed banks, from which they can establish new populations after the conditions for them have improved again. We found that in a well developed calcareous fen next to Belianske lúky 27 species formed a viable seed bank (Fig. 18), 14 of them were 'wanted' (mostly red list) species (among

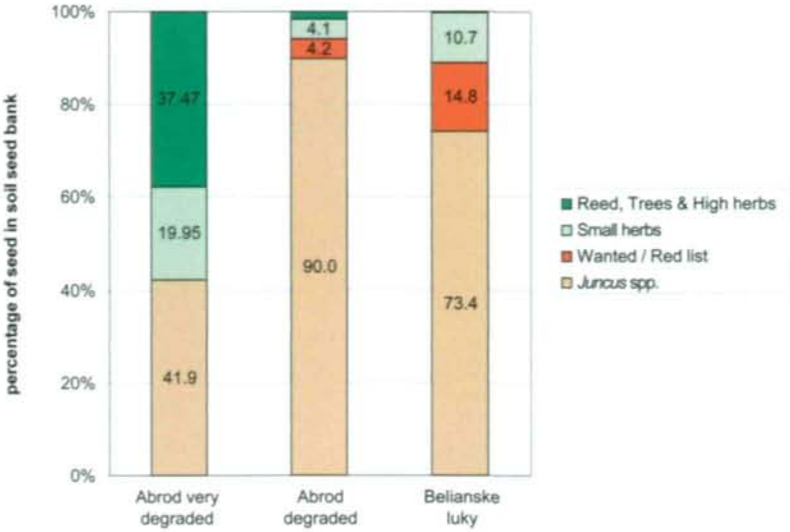


Fig. 18: Percentage of seeds in the soil seed bank in a very degraded fen meadow, a moderately degraded fen meadow and a well developed fen meadow.

them *Primula farinosa*). In a modest degraded fen meadow in Abrod 22 species formed a viable seed bank, of which 11 'wanted' species (Fig. 19 – 21). This meadow was regularly mown since and the biodiversity is still very high. A species-rich fen meadow could be restored, mostly from the seed bank, after tall birch (*Betula*) trees had overgrown the meadow 30 years ago. However, the seed bank had been completely depleted after 40 years in a former abandoned fen meadow that had been eutrophicated by severe drainage in summer and severe flooding in spring and autumn. The former species-rich fen meadow had changed into a highly productive *Urtica dioica* stand with *Phragmites australis*, *Calystegia sepium* and the tall herb *Solidago gigantea*. The total species pool of this site had been reduced to only 16 very common species. Only one fen meadow species had survived as seed (*Carex flava*). After 40 years, this site has become desiccated, partly due to deepening of the stream and the lack of management had led to accumulation of a thick layer of dead biomass in which none of the fen meadow species could survive.

Conservation is the primary key for maintaining most of the last remnants of endangered plant and animal species. Restoration is the second key. We should not overestimate the possibilities for hydrological

Fig. 19: *Dactylorhiza ochroleuca* (Photo J. Seffer)

Fig. 20: *Gladiolus palustris* (Photo J. Seffer)

restoration of damaged spring mires. It is almost impossible to restore the hydrology of a spring mire to its original situation with groundwater discharge at the top of the mire and slowly flowing groundwater through the upper peat layer. Once the peat has been drained, the organic matter becomes very compacted and the water flow becomes erosive and initiates tunnelling in the lower sections of the peat. If we want to prevent a total reconstruction of a mire, in which almost all remaining plant population will be sacrificed, it is unwise trying to 'push back' the water flow into the peat once it has been degraded. It is better to reduce the speed of the water by inserting small pebbles of calcareous stones in the stream. Building large dams is more costly and probably not effective in degraded spring mires (KOSKA & STEGMANN 2001). Reduced water flow will lead to increased formation of peat, because the moss species in particular, will gain new possibilities to establish a closed vegetation mat. Disturbed spring mires are self repairing systems, if we can stop peat erosion. Of course there are limits to this self repairing ability. If the water table fluctuations are very large, no possibilities exist for renewed peat growth and the peat will gradually decompose and acidify. Such changes have been observed in the Abrod fen meadow.

Our research has shown that the spring mires we studied are hydrologically still in a good condition. Nevertheless, they have experienced several periods of severe peat degradation, but always have found new ways and sites to recover and continue peat formation and travertine formation. Healthy spring mires just need sufficient space to respond to changes in the hydrology. That is why spring mires require buffer zones around them. And they need protection of their catchment area that supplies them with groundwater, which should be preferably forest. This prevents, both input of large amounts of nutrients, due to excessive fertilization of agricultural field, and it prevents rapid and erosive surface water flow.

Fig. 21: *Schoenus nigricans* (Photo J. SEFFER)

Acknowledgements

The Dutch government through its PIN/Matra programme made this research possible (PIN/Matra2001/033), while the Slovak Nature Conservation provided access to their nature reserves and also assisted actively in the research. Student and staff of the University of Groningen helped in collecting data during two field courses in Belianske lúky. Dr Michael Hajek of the Brno University and Dr. André Jansen gave valuable comments on an earlier version of the manuscript and also participated in the interpretation of the results. Mr D. Visser of the University of Groningen and Mr. Riki Watzka of DAPHNE helped to make the illustrations. Their help is gratefully acknowledged.

Zusammenfassung

Kalkreiche Niedermoore der Slowakei; Juwelen in der Krone des Reiches der Moore – Kalkreiche Niedermoore sind heute in der Slowakei fast nur noch in den Karpaten zu finden. Von den großen Beständen im Tiefland gibt es nur noch wenige Reste, die meisten wurden durch planmäßige Entwässerung zerstört. Die noch vorhandenen Flächen beherbergen allerdings noch eine

Reihe von Arten, die charakteristisch für Niedermoore und Feuchtwiesen sind, was bedeutet, dass sie in irgendeiner Weise gegen die sonst in Westeuropa übliche Niedermoor-Degradation abgepuffert sein müssen.

Das Ziel der vorliegenden Studie war, die Möglichkeiten für eine Renaturierung von kalkreichen Quellmooren zu erforschen, die entweder durch anthropogen bedingte Veränderungen im Wasserhaushalt oder durch fehlendes Management zerstört wurden. Die Untersuchungen wurden an zwei gut geschützten Quellmooren im Norden der Slowakei durchgeführt. Die Naturschutzgebiete Belianske lúky und Štrba sind typische und nur wenig gestörte Beispiele für die ehemals häufigen Kalk-Quellmoore der Slowakei. In beiden Gebieten führten wir eine ökohydrologische Analyse der Quellmoore durch, um herauszufinden, wie diese Lebensräume funktionieren und wie sie auf Veränderungen der hydrologischen Bedingungen reagieren. Darüberhinaus untersuchten wir auch die Nährstofflimits für die Vegetation und die versuchten an einigen ausgewählten Stellen die Überdauerungsfähigkeit der Samenbank im Boden abzuklären. Mit den Ergebnissen wollen wir dazu beitragen, dass adäquate Managementpläne für die Renaturierung dieser stark gefährdeten Lebensräume erstellt werden.

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